Data Center Energy Benchmarking:
Part 5 - Case Studies on a Corporate Data Center (No. 22)

Final Report

August 2007

Final Report Prepared by

Tengfang Xu and Steve Greenberg
Lawrence Berkeley National Laboratory (LBNL)
Berkeley CA 94720

Draft provided by

EYP Mission Critical Facilities
Los Angeles, CA 90064
and
Landsberg Engineering, P.C.
Clifton Park, NY 12065

Disclaimer

Table of Contents

1 Executive Summary

The data center in this study had a total floor area of 10,000 square feet (ft^2) with one-foot raised-floors. The data center housed 377 computer racks, and was located in a 110,000-ft^2 office building in Pasadena, California. However, the raised-floor was not utilized for cold air distribution. Communications and power wiring and fire sprinkler were located within the space above the ceiling. There were two standby generators, each rated at 1500 kW/kVA providing backup power supporting all building loads.

The building was served by a single 480-volt utility incoming service from Pasadena Water and Power Department (PWPD) serving the 4000-amp main distribution switchgear (see Figure 30 in Appendix B). The main switchgear fed four distribution switchboards. Two of the switchboards were supporting the critical loads via pairs of parallel-operated 500 kVA UPS modules. The other two switchboards supported the mechanical equipment and other miscellaneous building loads.

The data center operated on a 24 hour per day, year-round cycle, and users had all hour full access to the data center facility. Data center cooling was supplied by the main chilled water system to four air-handling units fitted with VSDs. The four air-handling units provided top flow ducted air supply to data center space. The AHU fan room return air was directly connected to the data center space, i.e., the return-air grille was on the wall separating the computer room from the return-air plenum. The AHUs had 4-inch throwaway air filters with 85% efficiency located at the front of the unit. The chilled water to the building was supplied by two Trane water-cooled chillers.

The study found that more than 80% of the electrical load was consumed by the data center: data center computer load accounted for 54% of the overall building electrical load. 21% of the load was consumed by AHUs, 5% by UPS', and 1% of the power was consumed by the data center lighting. The density of installed computer loads (rack load) in the data center was 57 W/ft^2. In addition, the data center accounted for additional cooling load provided by the chiller plants shared with the rest of the building. Power consumption density for all data center allocated load (including cooling and lighting) was 94 W/ft^2, approximately 10 times the average overall power density for the whole building.

For the data center, 60% of the overall electric power was the rack critical loads, 11% of the power was consumed by chillers, 22% by CRAH units, 6% by UPS', and 1% by lighting system.

General recommendations for improving overall data center energy efficiency include improving the lighting control, airflow optimization, control of mechanical systems serving the data center in actual operation. This includes chilled water system, airflow management and control in data centers. Additional specific recommendations or considerations to improve energy efficiency are provided in this report.

The data center had a total power density of approximately 94 W/ft^2, while the installed computer power density was 57 W/ft^2. The highest density of energy usage is from the racks. Therefore, it is important to reduce the rack power usage. General recommendations for improving overall data center energy efficiency include improving the lighting control, design, operation, and control of mechanical systems serving the data center in actual operation. This includes chilled water system, airflow management and control in data centers.

The following includes potential measures to improve the energy efficiency of the data center.

- Optimize air balance including reducing fan-wheel speeds as necessary

- Review proper control algorithms to ensure proper controls for the VSDs and AHUs. In particular, the supply air temperatures were generally lower than needed at the IT equipment. Improved air management would allow optimization with large chiller plant energy savings, and perhaps fan energy savings as well.

- Review operation of AHU-3. This unit had a relatively lower return air temperature which might indicate a possible “short-circuiting” of supply air to return air

- Optimize air management by reviewing placement of supply and return registers

- Consider raising chilled water supply water temperature. This can be done automatically using a worst-zone reset strategy to operate at the highest chilled water temperature that would meet the load. If chilled water temperature can be raised, the chiller plant would be more efficient and it would reduce incidental dehumidification, thus reducing the need for humidification as well.

- Optimize the operation of both cooling tower fans – both running together may produce the same heat rejection with much less energy than operating one single fan. In addition, consider resetting the cooling tower water temperature set points according to chiller manufacturer recommendations and/or outside air wet-bulb temperature plus an approach temperature. For any given load and wet-bulb temperature, there is an optimal combination of flow and temperature that can minimize overall chiller plant energy use. Software is available from manufacturers or consultants to optimize this algorithm.

- Install VSDs on the CHW primary pumps and the condenser water pumps and control per a chiller plant optimization routine. Check the operation of the generator jacket heaters. At least one heater appears to operate much more than necessary. The controls should be adjusted or replaced as needed.

- Check to see if the double-conversion UPS units can be operated in a bypass mode without sacrificing protection from power interruption.

2 Review of Site Characteristics

The corporate data center in this study had a total floor area of 10,000 square feet (ft^2) with one-foot raised-floors. The data center housed 377 computer racks, and was located in a 110,000-ft^2 office building in Pasadena, California. However, the raised-floor was not utilized for cold air distribution. Communications and power wiring and fire sprinkler were located within the space above the ceiling. There were two standby generators each rated at 1500 kW/kVA providing backup power supporting all building loads.

The building was served by a single 480-volt utility service from Pasadena Water and Power Department (PWPD) serving the 4000-amp main distribution switchgear (Figure in Appendix B). The main switchgear fed four distribution switchboards. Two of the switchboards supported the critical loads via pairs of parallel-operated 500 kVA UPS modules. The other two switchboards supported the mechanical equipment and other miscellaneous building loads.

The data center operated on a 24 hour per day, year-round cycle, and users had all hour full access to the data center facility. The data center did not have a dedicated chiller system but was served by the main building chiller plant connected to four air-handling units (AHUs) fitted with VSDs. The four air-handling units provided top flow ducted air supply to data center space. The AHU fan room return air was directly connected to the data center space, i.e., the return-air grille was on the wall separating the computer room from the return-air plenum. The AHUs had 4-inch throwaway air filters with 85% efficiency located at the front of the unit. The chilled water to the building was supplied by two Trane water-cooled chillers.

The data for this benchmarking exercise was collected during a one week monitoring period in December 2004. The data was collected using the following measurement instruments: HOBO loggers, Elite loggers, Fluke 41B power meter, K-20 and the building's Automatic Logic Corporation (ALC) system.

2.1 Electrical Equipment and Backup Power System

Electrical power to Data Center #22 was served by the building electrical distribution system, which received PWPD power via a three-phase, four-wire, 480/277-V main service, terminated to a 4,000A main distribution switchboard "MS." The main switchboard then sub-fed four separate distribution boards: "TPSA", "TPSB", "TPSC" and "TPSD." Distribution boards "TPSA" and "TPSB" supported the building data center critical loads, each distribution board serving four 500 kVA, double-conversion UPS modules. The diagram in Appendix B indicates two 500 kVA. The conditioned power from the UPS modules was distributed to the critical loads via two 3,000A, paralleling switchboard: "UPSA" and "UPSB". Distribution boards

"TPSC" and "TPSD" supported the mechanical equipment, lighting and other miscellaneous loads within the building.

The backup generation system consisted of two 1,500kW standby generators connected to a 4,000A paralleling switchgear "PS". There were two main distribution feeds from the paralleling switchgear, each terminated to a standby distribution bus located in the main switchboard "MS". The backup generation power supported the critical loads and the mechanical loads via normally-open circuit breakers that would be automatically closed during the normal power service interruption. There was no data available for PDUs.

A load monitoring device at the time of survey at the service entrance feeder of the main switchboard "MS" had indicated a reading average demand load from the utility service of 1,040 kW.

The backup generation system consists of two 1,500kW standby diesel generators - Model 3512B Engine, Model SR-4B.connected to a 4,000-A paralleling switchgear "PS". The generators had a total of four 15-kW block heaters. There were two 500 kW resistive load banks associated with each generator for testing. There were two main distribution feeds from the paralleling switchgear, each terminated to a standby distribution bus located in the main switchboard "MS". The backup generation power supported the critical loads and the mechanical loads via normally-open circuit breakers that would be automatically closed during the normal power service interruption.

2.2 Mechanical System

2.2.1 Chiller

The data center, along with the remainder of the building, was designed to be cooled by two 320-ton Trane CVHE 0450 multi-stage centrifugal direct drive water-cooled chillers. The chillers were arranged in a parallel configuration. The chillers were manually operated in a lead-lag alternate manner: only one chiller was in operation at the time of the study. The chillers were equipped with VSDs and were rated at 0.55 kW per cooling ton at 100% load, 0.44 kW per cooling ton at 75% load, and 0.33 kW per cooling ton at 30% load. The chiller had an operating chilled water temperature set point of 42°F and was controlled by the chilled water return temperature set point of 50°F through a Trane Tracer Summit system. The chilled water plant used chilled water reset in an effort to reduce chiller energy consumption.

2.2.2 Chilled Water Pump

Primary chilled water was circulated by two parallel Bell and Gossett centrifugal pumps, each with a motor capacity of 30 HP. The primary chilled water pumps were identified as CHWP-6 and CHWP-7. Only CHWP-7 was operating at the time of survey. The pump's discharge pressure was 48 psig and the suction pressure was 25 psig. The pumps were constant speed and were controlled by temperature sensors through the facilities building management system. The building operator manually switched the chiller from lead to lag operation. No information on specific sequence of operation regarding chiller and pump operation was available.

Figure 1 shows the chillers and chilled water pumps. Chilled water was circulated through the building secondary pumps by two 60-hp parallel–in line Bell and Gossett centrifugal pumps. The pumps were identified as CHWP-4 and CHWP-5. Both of the pumps were operating at the time of the survey. The pump discharge pressure gage reading was 44 psig and the suction pressure was 23 psig. The pumps were provided with variable speed drives, and were controlled via BMS based on chiller operation. Exact control sequence was not provided.

Figure 1 Chillers and chilled water pumps

2.2.3 Condenser Water Pump

Condenser water was supplied to the cooling towers by two 25-hp Bell and Gossett split case condenser water pumps. The pumps were arranged in parallel and identified as CWP-1 and CWP-2. Both pumps were constant speed and only CWP-2 was operating at the time of the survey. The condenser water pump discharge pressure gage reading was 68 psig and a suction pressure was 34 psig. The pumps were controlled by BMS based on chiller operation. Exact sequence of control was not recovded. At time of measurements, only one chiller was in operation.

2.2.4 Cooling tower

There are two 320-ton blow-through, closed-loop Evapco cooling towers Model UBW 207 with 30-hp fan motors. The cooling towers shown in Figure 2 were arranged in parallel and fitted with 30-hp fans and VSDs. The towers are identified as CT-1 and CT-2. Each tower had a capacity of 4,838 MBH with a design wet bulb temperature of 76°F, with entering water temperature of 97°F and leaving water temperature of 85°F. CT-1 was operating at the time of survey. The cooling tower fan speed was controlled by the tower's leaving water temperature. The exact set point reset schedule of condenser water supply temperature was however not available.

Figure 2 Cooling towers

2.2.5 Air Handling Unit

The data center was served by four Cel-Air air-handling units. Each air-handling unit was powered by a 40-hp fan motor fitted with a VSD. Each air handler had a cooling capacity of 350 MBH. Each air-handling unit had an air supply capacity of 30,000 cfm and the measured W/cfm was 1.7. The exact sequence of operation was not available. The air-handling units were identified as AHU-1 to AHU-4 and located at the fan room provided with a Very Early Smoke Detection Alarm (VESDA) smoke detection system.

The space temperature set point was 70°F. The air handlers are fitted with electric steam humidifiers. Exact control sequence for space relative humidity control was not provided. Each air handling unit supplied cold air to the ceiling space used as a supply plenum and cold air was distributed to the data center by overhead ceiling diffusers. There were no under-floor perforated tiles to supply cold air to this data center. The air return louvers of the fan room were directly connected to data center space facing south as shown in Appendix B.

AHU-1 had an average supply air temperature of 52°F and an average supply relative humidity of 61%. The return air temperature averaged 74°F with 31% RH. AHU-2 had an average supply air temperature of 53°F and an average supply relative humidity of 64%. The return air temperature averaged 74°F with 26% relative humidity. AHU-3 had an average supply air temperature of 53°F and an average supply relative humidity of 66%. The return air temperature averaged 69°F with 36% relative humidity. AHU-4 had an average supply air temperature of 53°F and an average supply relative humidity of 64%. The return air temperature averaged 73°F with 31% relative humidity. Figure 3 shows the AHU return-air plenum.

Figure 3 AHU return-air plenum

The UPS Room was served by two 15-hp air-handling units fitted with VSDs. Both units - AHU-5 and AHU-6 were operating at the time of the survey. Each AHUs had a design capacity of 22,500 cfm and measured W/cfm of 0.41.

The UPS/Battery Room was served by two 7.5-hp air handling units fitted with VSDs. Both units were operating at the time of the survey. AHU-7 and AHU-8 had capacities of 6,500 cfm each and measured W/cfm of 0.19.

The Electric Room was served by two 3-hp air-handling units fitted with VSDs. Both units were operating at the time of the survey. AHU-9 and AHU-10 had capacities of 3,750 cfm each and measured W/cfm of 0.45.

3 Electric Power Consumption Characteristics

Table 1 shows the end-use electricity demand of the building housing the data center in this study, based on the measurements taken during the monitoring period. The average building electrical load of 1039 kW was recorded from building instruments. The table also includes power density for the square foot area served by each load. Table 2 further shows the power demand and power density of the load within the data center.

From these measurements, it was observed that more than 80% of the electrical load was consumed by the data center: 54% of the load was consumed by the data center computer equipment, 21% of the load was consumed by AHUs, 5% by UPS', and 1% of the power was consumed by the data center lighting. In addition, the data center accounted for additional cooling load provided by the chiller plants shared with the rest of the building.

Table 2 indicates that for the data center, 60% of the overall electric power was the rack critical loads, 11% of the power was consumed by chillers, 22% by all AHUs, 6% by UPS', and 1% by lighting system. The density of installed computer loads (rack load) in the data center was 57 W/ft^2. Power consumption density for all data center load (including cooling and lighting) was 94 W/ft^2, approximately ten times the average power density of the overall building.

Table 1. End-Use of Electricity of the Data Center Building

Description	Electric power demand (kW)	Share of electric energy use (%)	Floor Space (ft2)	Electric power density (W/ft2)
Overall Building Load	**1,039**	**100%**	**110,000**	**9.5**
Data Center Rack Power	**565**	**54%**	**10,000**	**56.5**
Data Center UPS Losses	**44**	**4%**	**10,000**	**4.4**
AHUs Data Center	**205**	**20%**	**10,000**	**20.5**
AHUs UPS/Battery/Elec	**12**	**1%**	**10,000**	**1.2**
Total Chiller Plant	**142**	**14%**	**110,000**	**1.3**
Building Chillers	82	**8%**	110,000	0.8
Building Pumps	49	**5%**	110,000	0.5
Building Cooling Towers	10	**1%**	110,000	0.1
Building Generator Heaters	**59**	**6%**	**110,000**	**0.5**
Data Center Lighting	**13**	**1%**	**10,000**	**1.2**

Table 2. End-Use of Electricity of the Data Center

Description	Electric power demand (kW)	Share of electric energy use (%)	Floor Space (ft2)	Electric power density (W/ft2)
Data Center Rack Power	**565**	**60%**	**10,000**	**56.5**
Data Center UPS Losses	**44**	**5%**	**10,000**	**4.4**
AHUs Data Center	**205**	**22%**	**10,000**	**20.5**
AHUs UPS/Battery/Elec	**12.2**	**1%**	**10,000**	**1.2**
Building Chiller Plant (A)	**106**	**11%**	**10,000**	**10.6**
Building Chillers (A)	**61**	**7%**	**10,000**	**6.1**
Building Pumps (A)	37	**4%**	10,000	3.7
Building Cooling Towers (A)	8	**1%**	10,000	0.8
Data Center Lighting	13	**1%**	10,000	1.3
Total Data Center Only	**944**	**100%**	**10,000**	**94.4**

3.1 Power System

The main electrical incoming service provided support to the critical loads via a pair of redundant 3,000A, 480V main service buses, feeding multiple panels within the building. The data center was fed through four 500 kVA UPS units. The chillers, pumps, CRAC units lighting and miscellaneous loads were fed from other panels.

3.2 Chiller System

Electric power demand was monitored for the two operating chillers within a one-week period. Chiller CH-1 provided the majority of the cooling load with average power consumption of 82 kW. Chiller CH-2 was in operation occasionally. The total chiller power consumption for the period average 82 kW. For the monitoring period, the ambient air temperature averaged 61°F, while the ambient relative humidity averaged 61%.

Figure 4 shows the scatter plot of total chiller power consumption and outside air temperature. Except for a few occasions when two chillers were simultaneously on, the variations in total chiller power demand showed essentially non-significant correlation with the outdoor air temperature. As the outside air temperature changed, the actual chiller power demand didn’t exhibit similar changes. Since most of the load on the chiller is as a result of the data center, the impact of ambient temperature on cooling load is minimal.

The primary chilled water loop was designed for 640 gpm water flow rate. With an average temperature differential over the monitoring period of 8.3°F, the average cooling load was about 220 tons.

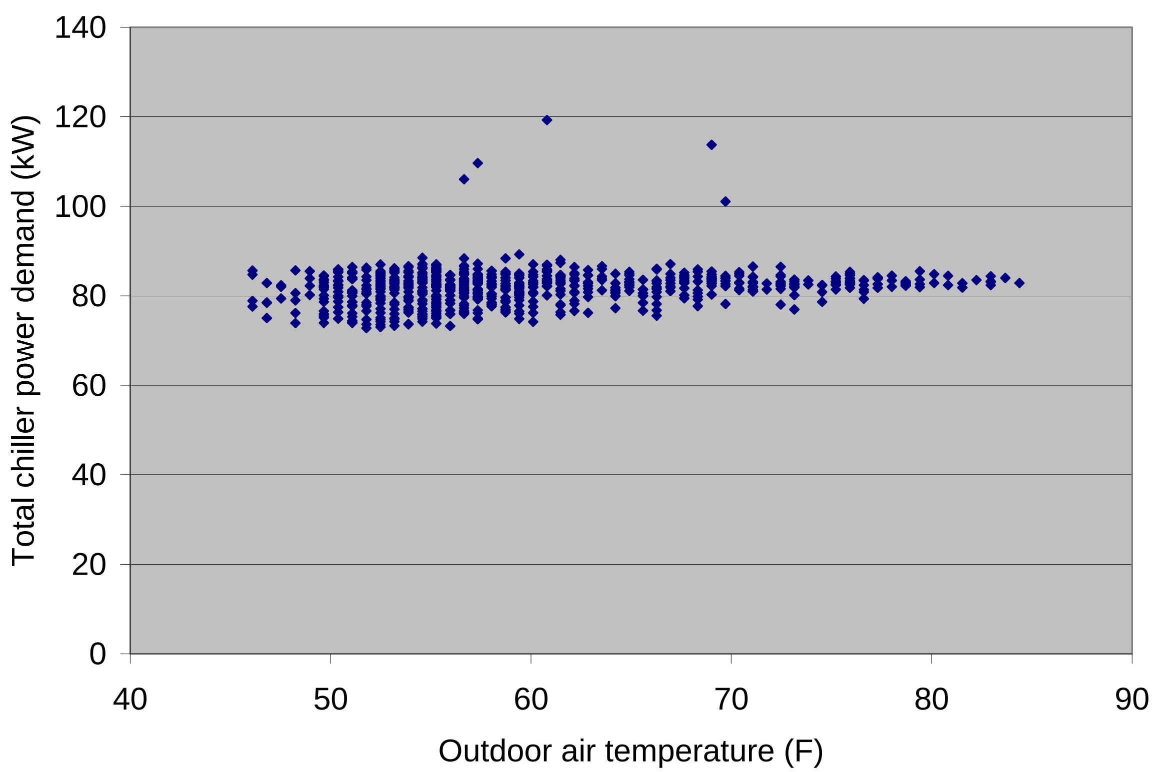

Figure 4 Correlation of chiller cooling power and outdoor air temperature

3.3 Pumping System

The building was served by two 30-hp primary chilled water pumps: CHWP-6 and CHWP-7. Only one pump was operational at any given time. For the pump monitored (CHWP-7 controlled with Chiller 2), the power demand of the primary pump was 19 kW when in operation . The primary chilled water loop was designed at 640 gpm.

The secondary chilled water pumps (CHWP-5 and CHWP-6) were 60-hp units fitted with VSDs. The secondary chilled water loop was designed at 1,280 gpm at full load. The average power demand was 8 kW for CHWP-5 and 10 kW for CHWP-6 (Figure 5). The recorded data shows that the chilled water pumps were in operation in majority of the time during the study but one of the pump appeared to stop operation since Monday afternoon (Jan 24, 2005), while the other pump joined the idleness starting in the mid-week, Wednesday afternoon (January 26, 2005). This indicates that it's advisable to check the operation and data acquisition system.

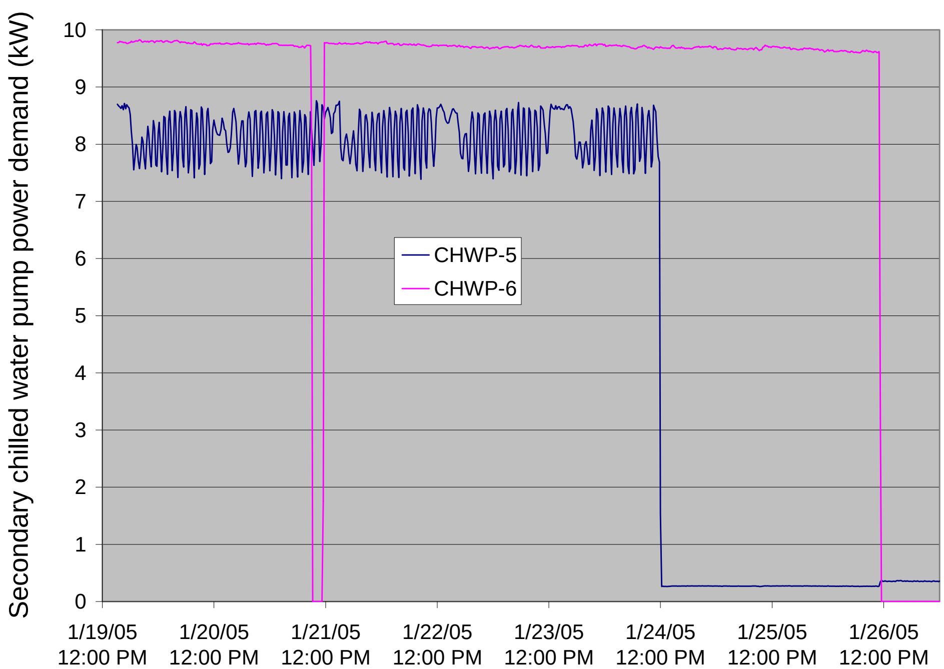

Figure 5 Chilled Water Pump Power Demand

Condenser water pumps (CWP-1 and CWP-2) were designed for 800 gpm at full load. Both pumps were 25-hp units fitted with motor starters.. The pumps operated alternately, with an average power demand of approximately 17kW when the pumps were operating (Figure 6).

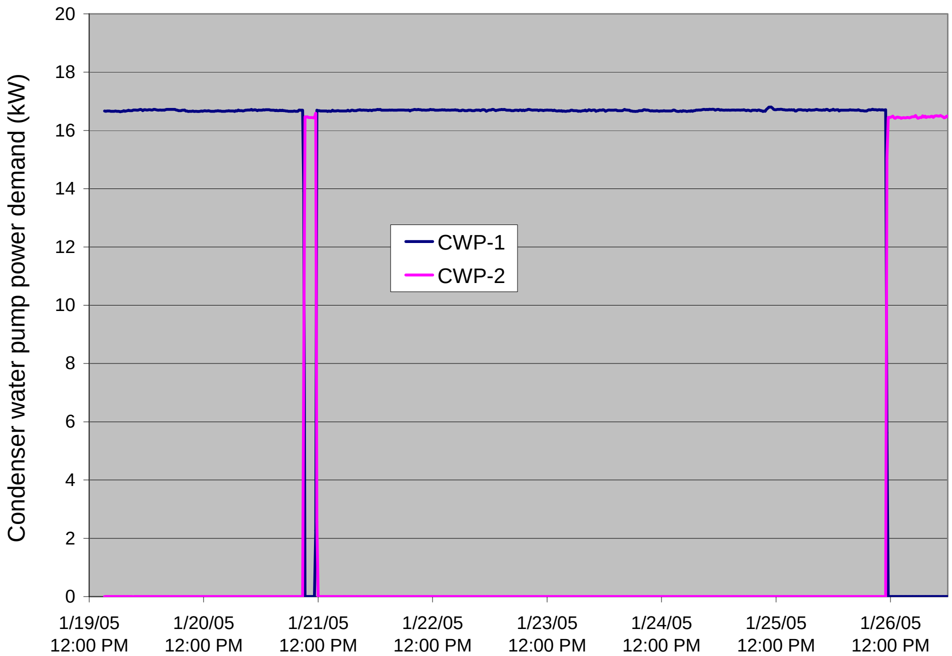

Figure 6 Condenser Water Pump Power Demand

3.4 Cooling Towers and Pumps

The two cooling towers, CT-1 and CT-2 each had one 30-hp fan fitted with a VSD. The units operated alternately at the time of the survey. Figure 7 shows the power demand of the two cooling tower fans that were in alternate operation during the study. Diurnal variation in power consumption was apparent. Power consumption averaged 10.4 kW for the monitoring period, with highs near 25 kW during afternoon peak hours, and lows under 4 kW toward early mornings.

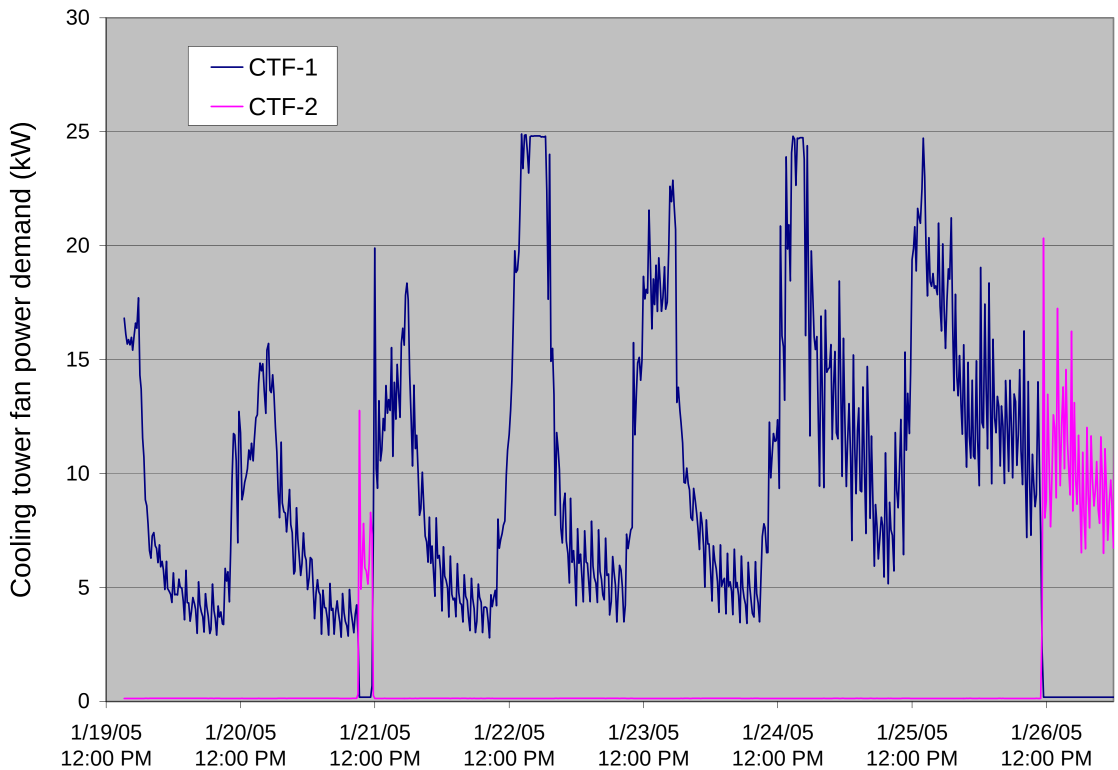

Figure 7 Cooling tower fan power

3.5 Emergency Generators

There were two 1,500 kW Caterpillar engine electric generators. The units were fitted with two 15-kW water jacket heaters each. We monitored the power use of one of the jacket heaters, which were on almost continually and averaged 14.8 kW over the monitoring period. Assuming that four heaters were on in the similar pattern, the total power demand from the heaters was 59 kW.

3.6 AHU Power Consumption

The data center was served by four air handling units, supplying 30,000 cfm each and fitted with 40-hp fans and VSDs. All four units were in operation at the time of the study. Power demand of the four units were recorded and showed an average of 1.7 W per cfm supplied.

The UPS Room was served by two 15-hp air-handling units fitted with VSDs. Both AHUs (AHU-5 and AHU-6) were in operation at the time of the study. AHU-5 and AHU-6 had capacities of 22,500 cfm each and measured W/cfm of 0.41.

The UPS/Battery Room was served by two 7.5-hp air handling units fitted with VSDs. Both units (AHU-7 and AHU-8) were in operation at the time of the survey. AHU-7 and AHU-8 had capacities of 6,500 cfm each and measured W/cfm of 0.17. Figure 8 shows the power demand of AHU 8 over the monitoring period, with a minimum of 1.05 kW to a maximum of 1.17 kW and an average of 1.1 kW.

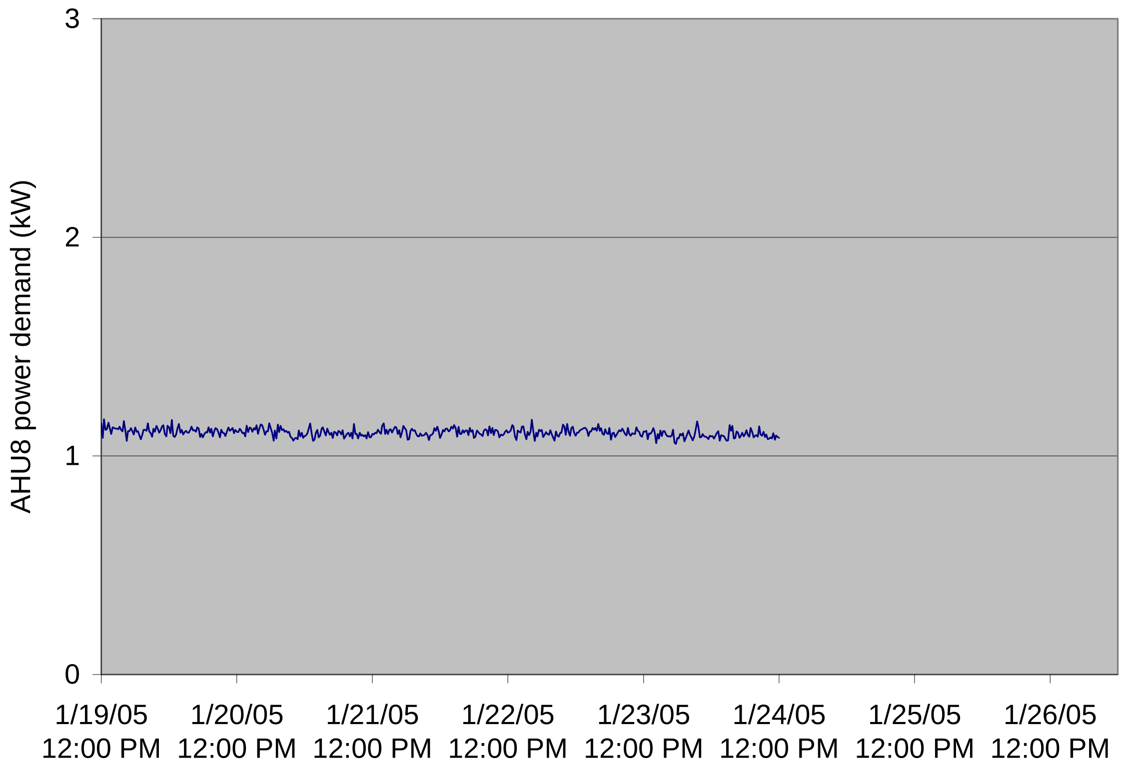

Figure 8 AHU8 power demand

The Electric Room was served by two 3-hp air handling units fitted with VSDs. Both units (AHU-9 and AHU-10) were in operation at the time of the study. AHU-9 and AHU-10 had capacities of 3,750 cfm.

4 System Operation

During the one-week monitoring period, the following HVAC equipment was operating:

- Primary chilled water pumps CHWP-6 and CHWP-7 (alternating)
- Secondary chilled water pumps CHWP-4 and CHWP-5
- Chillers CH-1, CH-2 (alternating)
- Condenser Pumps CWP-1 and CWP-2 (alternating)
- Cooling tower fans CTF-1 and CTF-2 (alternating)

- All four data center air handling units

4.1 Chilled Water Supply and Return Temperatures

The chilled water supply and return temperatures were recorded. For the monitoring period, the average chilled water supply temperature was 42°F while the average chilled water return temperature was 50°F. This produced an average temperature differential of 8°F. The temperatures were stable during the monitoring period.

4.2 Air Handler Unit Supply and Return Temperatures and Relative Humidity

Figure 9 shows supply air temperature and relative humidity for AHU-1. The supply air temperature averaged 52°F while the supply relative humidity averaged 67% RH. The return air temperature averaged 74°F, while the return air relative humidity averaged 31% RH.

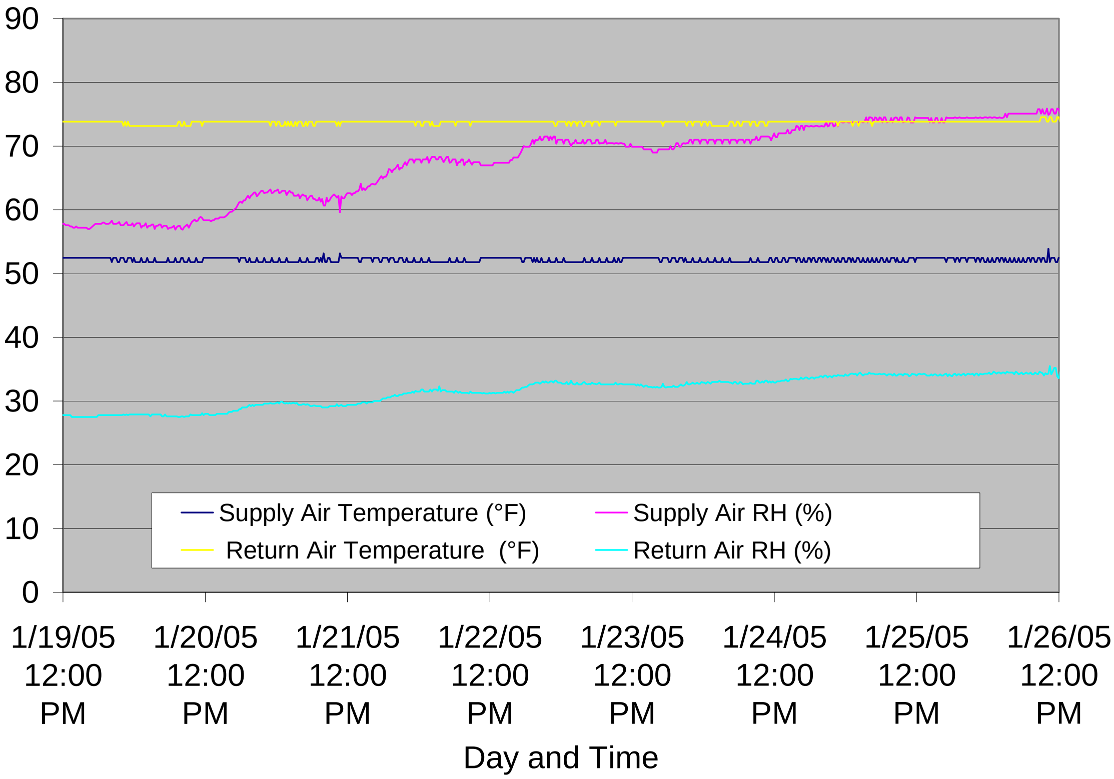

Figure 9 AHU-1 Air Temperature and Humidity

Figure 10 shows supply air temperature and relative humidity for AHU-2. The supply air temperature averaged 53°F while the supply relative humidity averaged 64%. The return air temperature averaged 74°F, while the return air relative humidity averaged 26%.

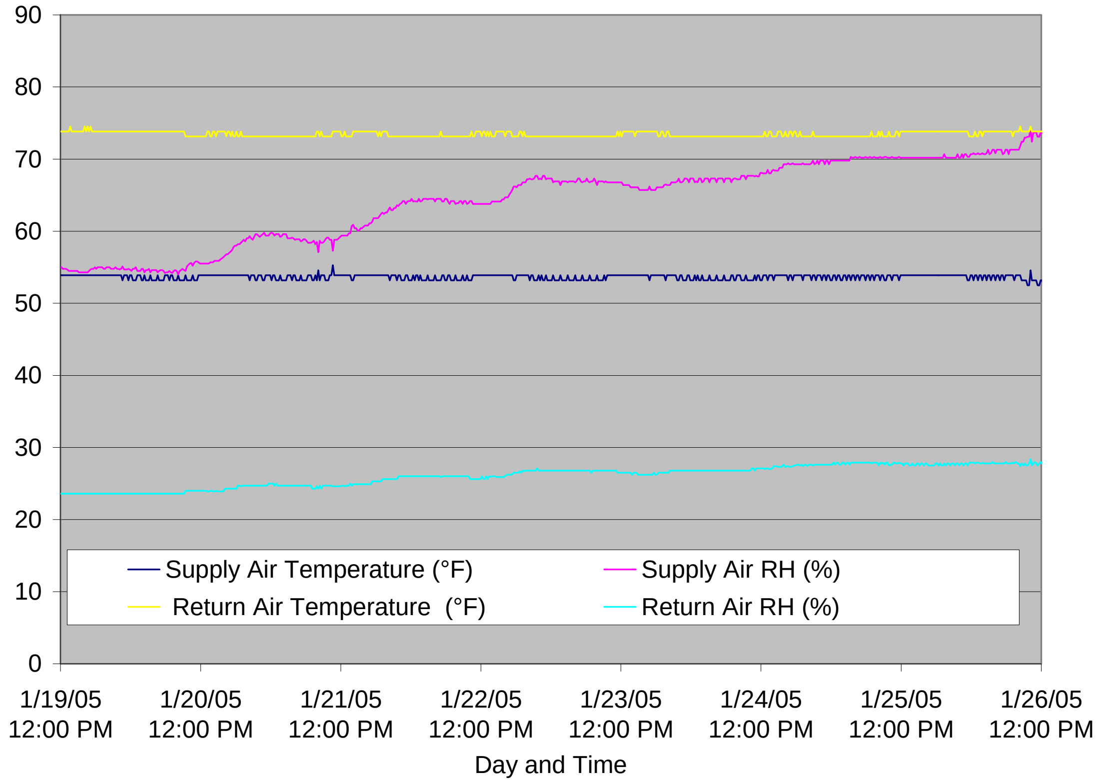

Figure 10 AHU-2 Air Temperature and Humidity

Figure 11 shows supply air temperature and relative humidity for AHU-3. The supply air temperature averaged 53°F while the supply relative humidity averaged 66%. The return air temperature averaged 69°F, while the return air relative humidity averaged 36%.

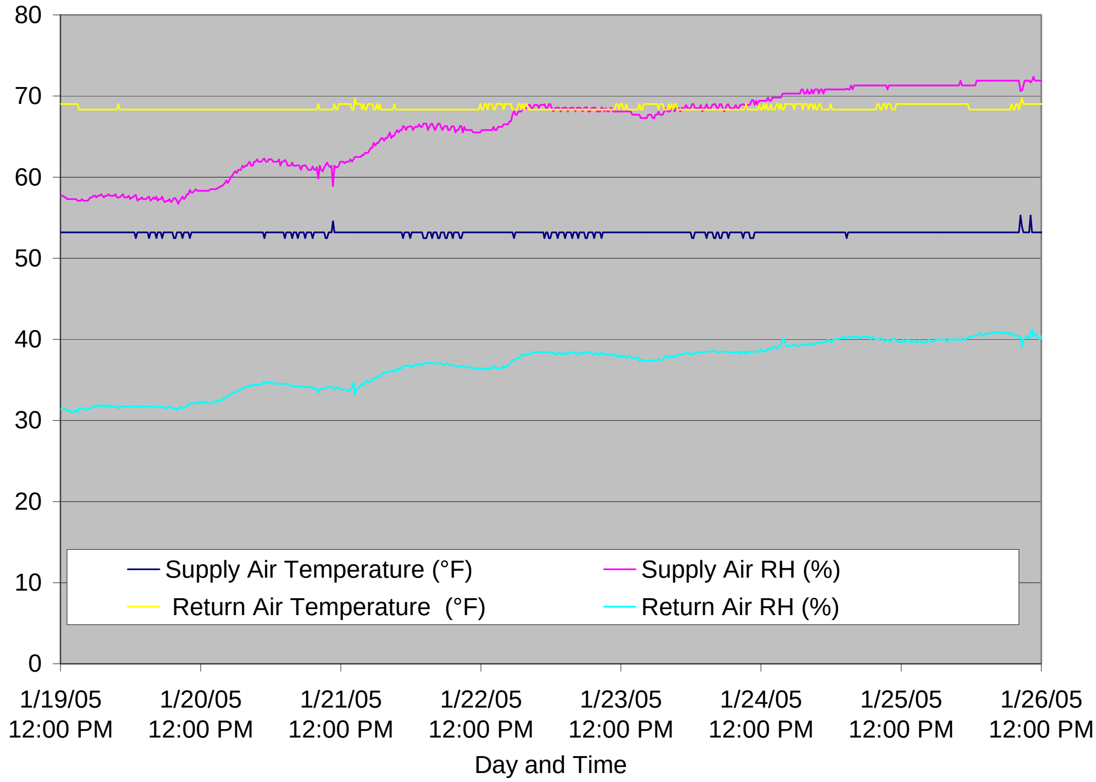

Figure 11 AHU-3 Air Temperature and Humidity

Figure 12 shows the return air temperature and relative humidity for AHU-4. The supply air temperature averaged 53°F while the supply relative humidity averaged 64%. The return air temperature averaged 73°F, while the return air relative humidity averaged 31%.

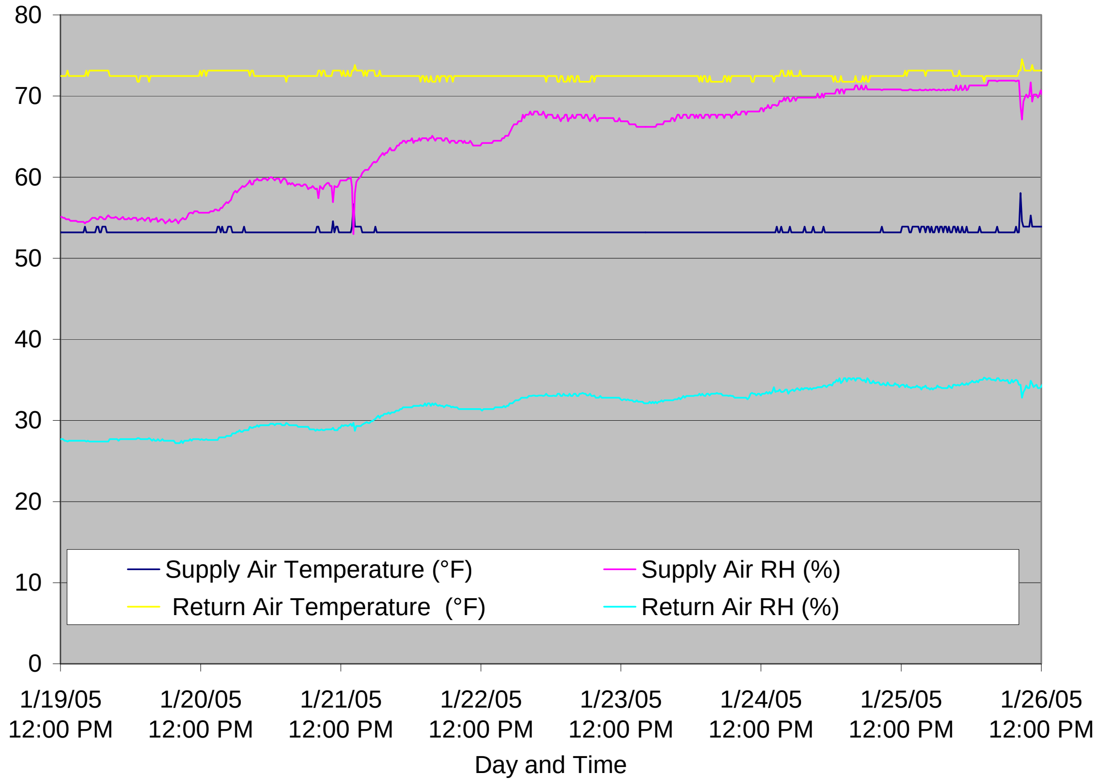

Figure 12 AHU-4 Air Temperature and Humidity

4.3 Data Center Air Conditions

Air temperature and relative humidity was recorded at two locations in the data center, as shown in Figure 13. The average space conditions were 67°F and 35% RH at one location and 69°F and 38% RH at the other location.

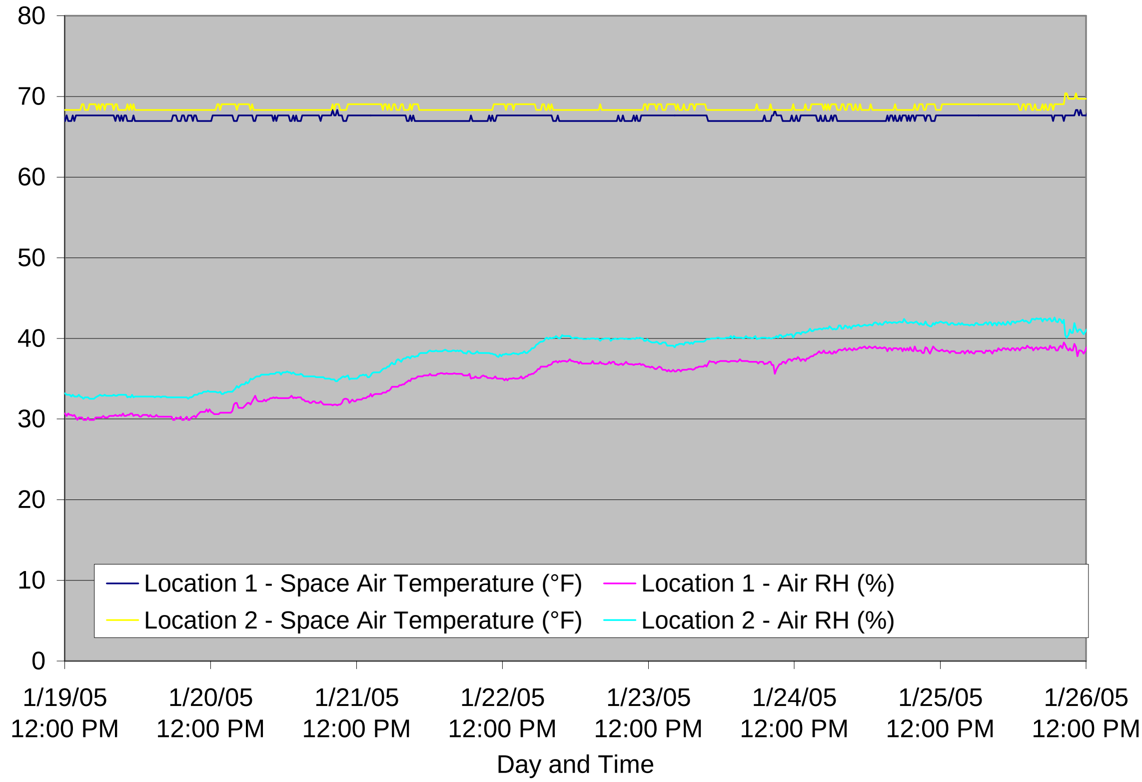

Figure 13 Space Air Temperature and Humidity at Two Locations

Generator coolant inlet and outlet temperatures were monitored in the study, as shown in Figure 14 and Figure 15, respectively. The temperatures averaged 65°F and 64°F, respectively.

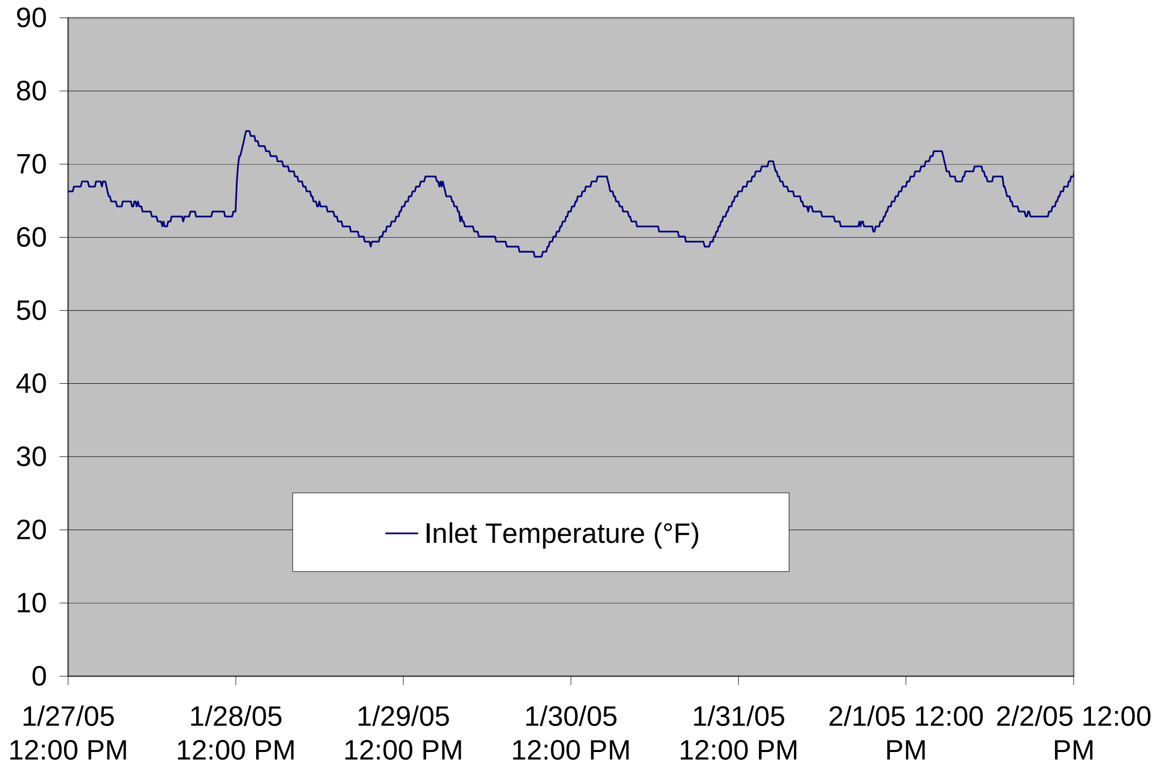

Figure 14 Generator Coolant Inlet Temperature

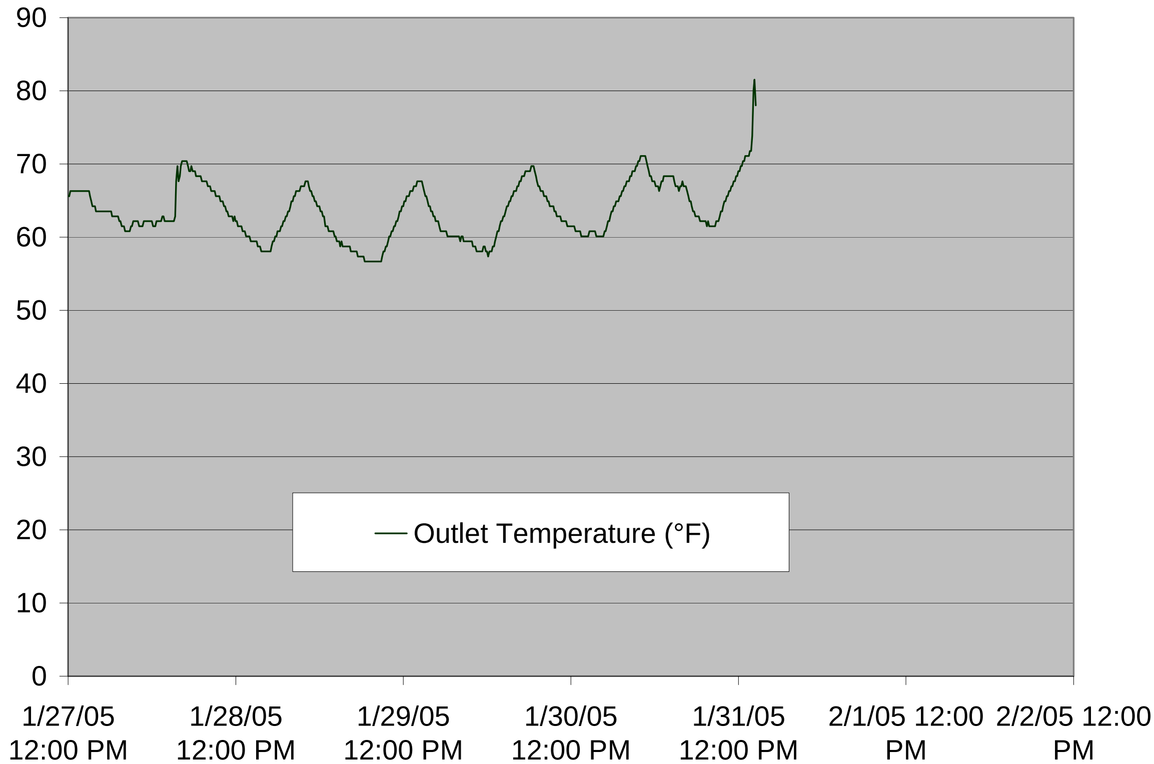

Figure 15 Generator Coolant Outlet Temperature

5 Observations and Recommendations

The data center had a total power density of approximately 94 W/ft^2, while the installed computer power density was 57 W/ft^2. The highest density of energy usage is from the racks. Therefore, it is important to reduce the rack power usage.

General recommendations for improving overall data center energy efficiency include improving the lighting control; design, operation, and control of mechanical systems serving the data center in actual operation. This includes the air-handling equipment, the chilled water system, configuration and control of airflow management in the data center.

The second highest power intensity was the air handling units serving the data center (21 W/ft^2). Several measures may be considered to reduce the power intensity of the AHU systems:

- Optimize air balance including reducing fan-wheel speeds as necessary

- Review proper control algorithms to ensure proper controls for the VSDs and AHUs. In particular, the supply air temperatures were generally lower than needed at the IT equipment. Improved air management would allow optimization with large chiller plant energy savings, and perhaps fan energy savings as well.

- Review operation of AHU-3. This unit had a relatively lower return air temperature which might indicate a possible “short-circuiting” of supply air to return air

- Optimize air management by reviewing placement of supply and return registers

The following includes potential measures to improve the energy efficiency of the data center.

- Consider raising chilled water supply water temperature. This can be done automatically using a worst-zone reset strategy to operate at the highest chilled water temperature that would meet the load. If chilled water temperature can be raised, the chiller plant would be more efficient and it would reduce incidental dehumidification, thus reducing the need for humidification as well.

- Optimize the operation of both cooling tower fans – both running together may produce the same heat rejection with much less energy than operating one single fan. In addition, consider resetting the cooling tower water temperature set points according to chiller manufacturer recommendations and/or outside air wet-bulb temperature plus an approach temperature. For any given load and wet-bulb temperature, there is an optimal combination of flow and temperature that can minimize overall chiller plant energy use. Software is available from manufacturers or consultants to optimize this algorithm.

- Install VSDs on the CHW primary pumps and the condenser water pumps and control per a chiller plant optimization routine. Check the operation of the generator jacket heaters. At least one heater appears to operate much more than necessary. The controls should be adjusted or replaced as needed.

- Check to see if the double-conversion UPS units can be operated in a bypass mode without sacrificing protection from power interruption.

6 Acknowledgements

This report on data center energy benchmarking was finalized based upon the field data collection performed by EYP Mission Critical Facilities and Landsberg Engineering and the draft report produced in the course of performing work subcontracted for the Lawrence Berkeley National Laboratory (LBNL).

The project was funded by the California Energy Commission’s Industrial section of the Public Interest Energy Research (PIER) program. This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology, State, and Community Programs, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

7 Appendix A: Data Facility Definitions and Metrics

The following definitions and metrics are used to characterize data centers:

Air Flow Density	The air flow (cfm) in a given area (sf).
Air Handler Efficiency 1	The air flow (cfm) per power used (kW) by the CRAC unit fan.
Air Handler Efficiency 2	The power used (kW), per ton of cooling achieved by the air-handling unit.
Chiller Efficiency	The power used (kW), per ton of cooling produced by the chiller.
Computer Load Density – Rack Footprint	Measured Data Center Server Load in watts (W) divided by the total area that the racks occupy, or the "rack footprint".
Computer Load Density per Rack	Ratio of actual measured Data Center Server Load in watts (W) per rack. This is the average density per rack.
Computer/Server Load Measured Energy Density	Ratio of actual measured Data Center Server Load in watts (W) to the square foot area (sf) of Data Center Floor. Includes vacant space in floor area.
Computer/Server Load Projected Energy Density	Ratio of forecasted Data Center Server Load in watts (W) to the square foot area (sf) of the Data Center Floor if the Data Center Floor were fully occupied. The Data Center Server Load is inflated by the percentage of currently occupied space.
Cooling Load – Tons	A unit used to measure the amount of cooling being done. One ton of cooling is equal to 12,000 British Thermal Units (BTUs) per hour.
Data Center Cooling	Electrical power devoted to cooling equipment for the Data Center Floor space.
Data Center Server/Computer Load	Electrical power devoted to equipment on the Data Center Floor. Typically the power measured upstream of power distribution units or panels. Includes servers,

	switches, routers, storage equipment, monitors and other equipment.
Data Center Facility	A facility that contains both central communications and equipment, and data storage and processing equipment (servers) associated with a concentration of data cables. Can be used interchangeably with Server Farm Facility.
Data Center Floor/Space	Total footprint area of controlled access space devoted to company/customer equipment. Includes aisle ways, caged space, cooling units electrical panels, fire suppression equipment and other support equipment. Per the Uptime Institute Definitions, this gross floor space is what is typically used by facility engineers in calculating a computer load density (W/sf).
Data Center Occupancy	This is based on a qualitative estimate of how physically loaded the data centers are.
Server Farm Facility	A facility that contains both central communications and equipment, and data storage and processing equipment (servers) associated with a concentration of data cables. Can be used interchangeably with Data Center Facility. Also defined as a common physical space on the Data Center Floor where server equipment is located (i.e. server farm).

8 Appendix B: Facility Diagrams

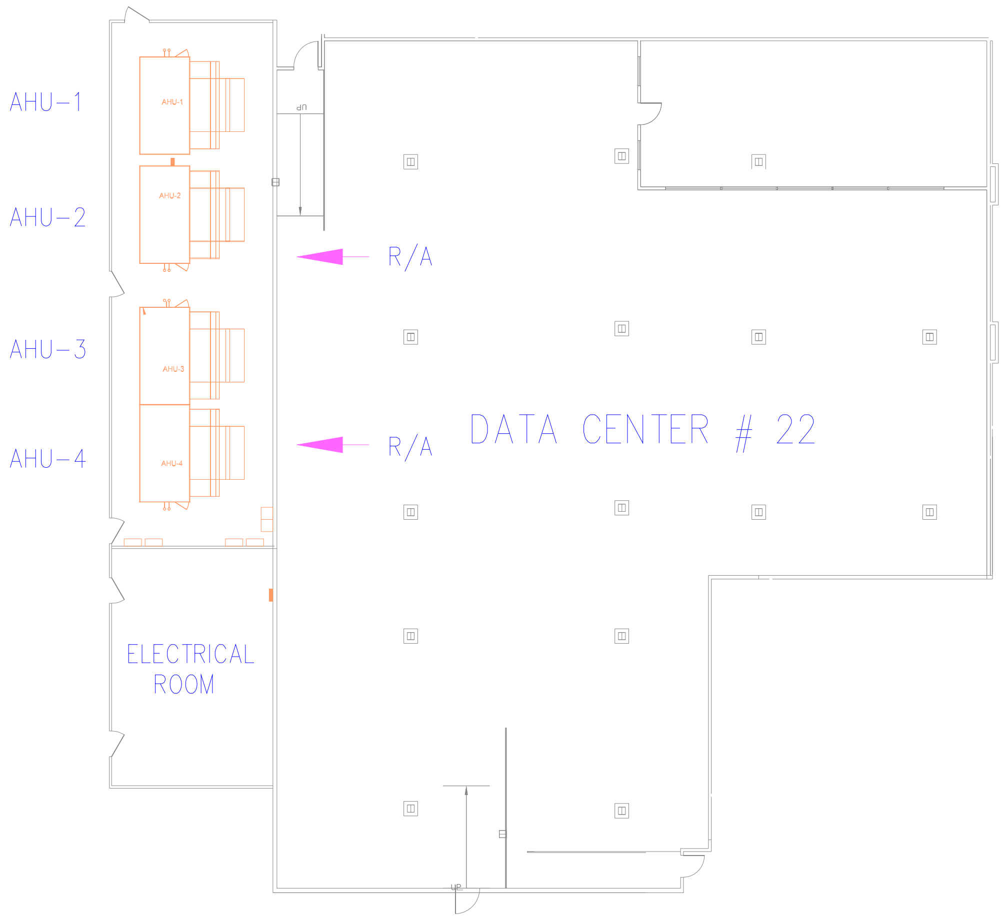

Figure 16. Data Center Plan Layout

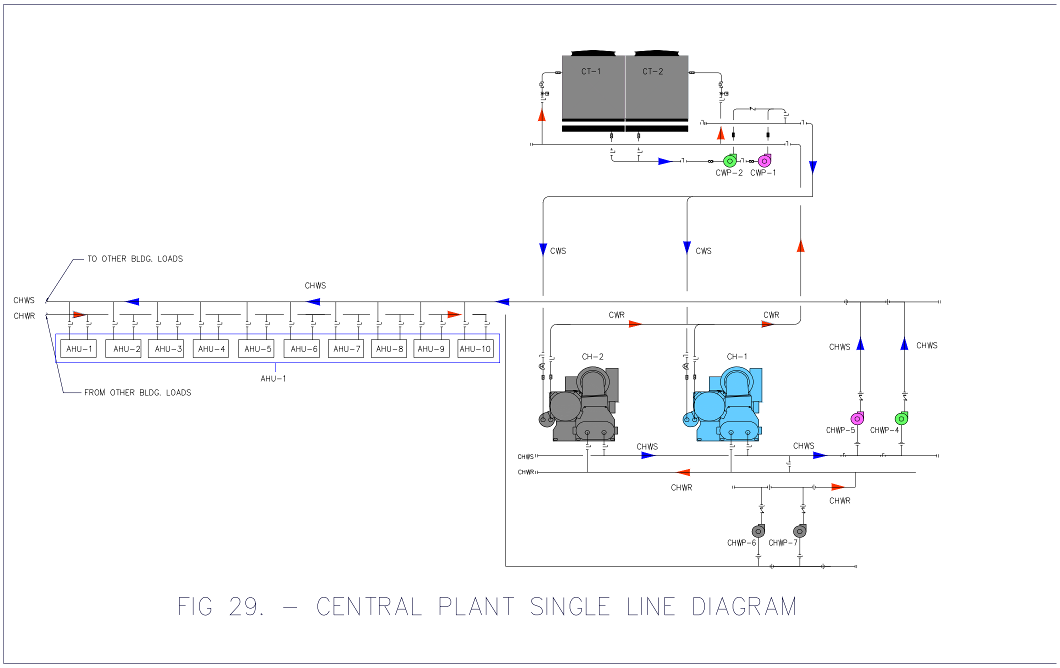

Figure 17. Chilled Water System

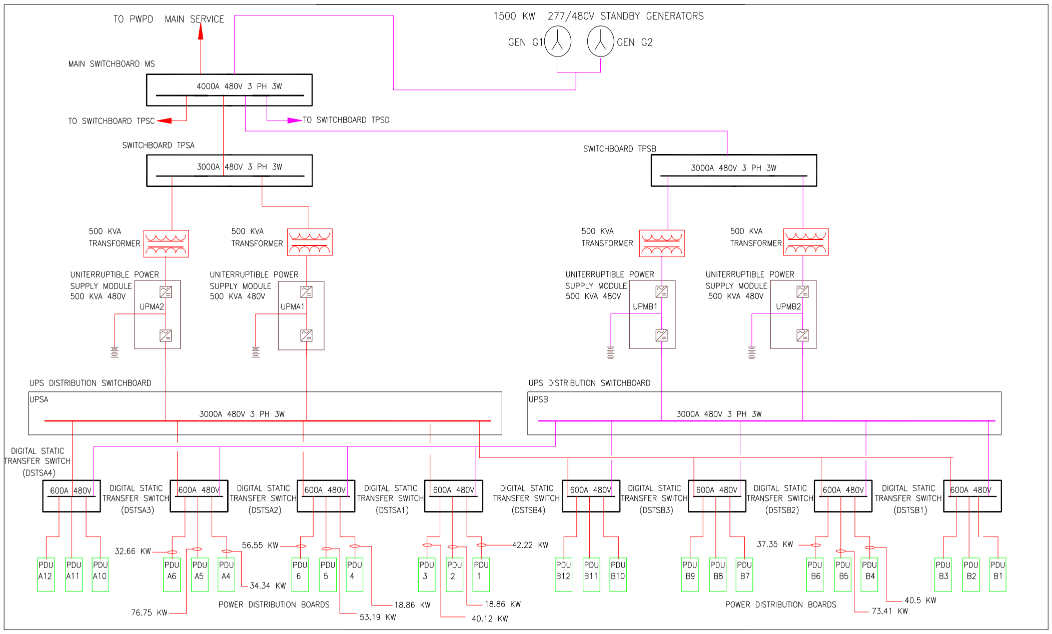

FIGURE 30 – ELECTRICAL SYSTEM SCHEMATIC

Figure 18. Electrical System Schematic

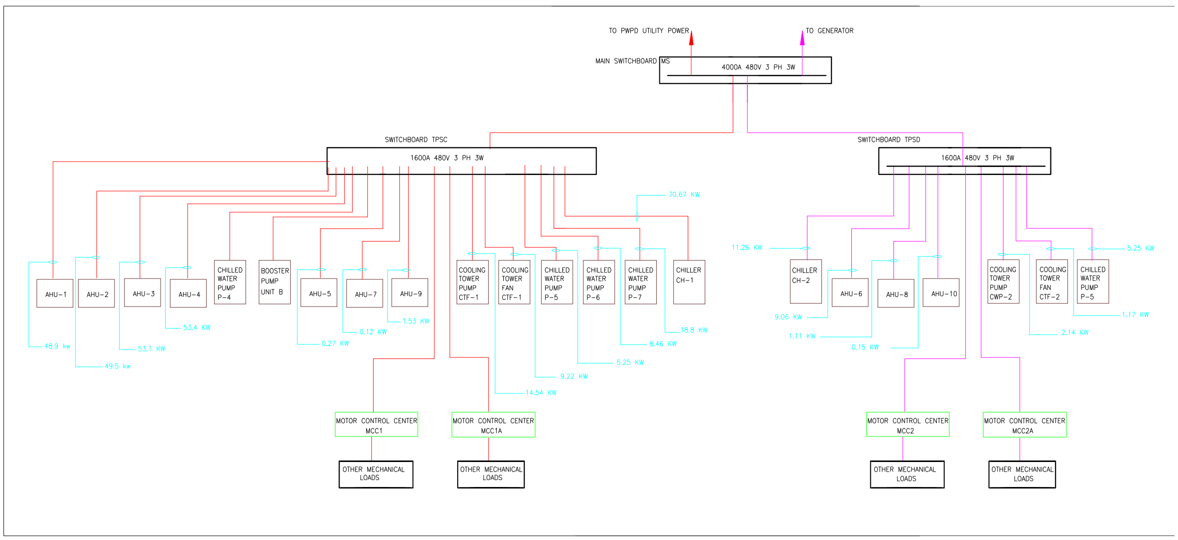

FIGURE 31 – ELECTRICAL SYSTEM SCHEMATIC TO MECHANICAL LOADS

Figure 19. Mechanical Loads and Electrical System